Precipitation Reactions and Net Ionic Equations

WHY?

Writing reaction equations is a way of predicting what reactions will take place between two substances. Sometimes our "paper and pencil" chemistry disagrees with what we see in the lab. When aqueous solutions of compounds are mixed some reactions are observed to occur while other do not. We resolve this conundrum by using a notation called *net ionic equations* that we will learn about in this activity.

Before you begin you should understand:

- Naming of binary compounds and writing chemical formulae
- Writing and balancing chemical equations
- Naming of polyatomic ions

Before you leave today you should be able to:

- Predict products for double displacement reactions.
- Apply solubility rules to predict the solubility of an ionic compound.
- Write molecular, ionic and net ionic equations given the reactants of a chemical reaction.

Definitions

A *solution* is a homogeneous mixture of a solid, liquid or gas in a liquid. The liquid present in greatest amount is called the *solvent*. Whatever is dissolved in the liquid is called the *solute.*

An *aqueous* solution is a solution where the solvent is water.

A compound is said to be *soluble* if it readily dissolves in water and does not fall out of solution (*precipitate*) if left for an extended period of time.

Model I: Rules of Solubility in Aqueous Solutions

The following solid compounds are taken and placed in water to determine if they are soluble. The results are shown in the charter below. An X indicates that the compound will not dissolve in water. If it does dissolve no mark is made.

Precipitation Reactions and Net Ionic Equations

The top row shows the cation of the compound. The far left column shows the anion of the compound. For example, $Mg(OH)_2$ is insoluble. $MgBr_2$ is soluble. AgCl is insoluble.

	NH_4^+	Li^+	Na^+	K^+	Mg^+	Ca^{2+}	Sr^{2+}	Ba^{2+}	Ag^+	Pb^{2+}	Hg_2^{2+}	Fe^{3+}	Cu^{2+}	Zn^{2+}
NO_3^-														
$C_2H_3O_2^-$														
ClO_3^-														
Cl^-									X	X	X			
Br^-									X	X	X			
I^-									X	X	X			
SO_4^{2-}						X	X	X	X	X	X			
OH^-					X				X	X	X	X	X	X
S^-					X	X	X	X	X	X	X	X	X	X
CO_3^{2-}					X	X	X	X	X	X	X	X	X	X
PO_4^-					X	X	X	X	X	X	X	X	X	X
CrO_4^{2-}					X	X	X	X	X	X	X	X	X	X

Key Questions:

1. Is calcium carbonate soluble or insoluble?
2. Is silver bromide soluble or insoluble?
3. Is iron (III) sulfate soluble or insoluble?
4. For what cations are the compounds <u>always soluble</u> in water?
5. For what anions are the compounds <u>always soluble</u> in water?
6. For what anions are most of the compounds <u>usually soluble</u> (with some exceptions)?
7. For these anions that usually form soluble compounds, which cations result in the formation of insoluble compounds?
8. For what anions are most of their compounds usually <u>insoluble</u>?
9. What patterns can be found in your answers to questions 4, 5 and 6? Consider the location of the elements on the periodic table as you develop your response.

Precipitation Reactions and Net Ionic Equations

Exercise:

1. Propose a short set of rules that summarize a way to predict which compounds are soluble and which are not.

Compounds with these ions are SOLUBLE (aq)	**Exceptions that are SOLID (s)**
Compounds with these ions are INSOLUBLE (s)	**Exceptions that are SOLUBLE (aq)**

2. Write the correct chemical formula for each compound below, than determine whether each of the following compounds are soluble or insoluble using the solubility rules you created above. Circle the insoluble compounds. Double check by comparing with the table above.

a. Silver iodide	b. Strontium hydroxide	c. calcium sulfate
d. sodium phosphate	e. barium acetate	f. magnesium carbonate
g. potassium nitrate	h. zinc carbonate	i. copper (II) sulfide
j. lead (II) carbonate	k. sodium acetate	l. Iron (III) sulfide

Precipitation Reactions and Net Ionic Equations

Solubility rules

The observations above are summarized according to the solubility rules.

All compounds containing Group I ions and NH_4^+ are soluble

All compounds containing acetate ($C_2H_3O_2^-$) and nitrate (NO_3^-) and chlorate (ClO_3^-) are soluble

All compounds containing chloride (Cl^-), bromide (Br^-) and iodide (I^-) are soluble except Ag^+, Hg_2^{2+} and Pb^{2+} which are insoluble

All compounds containing sulfate (SO_4^{2-}) are soluble except Ca^{2+}, Sr^{2+}, Ba^{2+}, Hg_2^{2+}, Ag^+ and Pb^{2+} which are insoluble

All compounds containing hydroxide (OH^-) and oxide (O^{2-}) are insoluble except Group I and Ca^{2+}, Sr^{2+} and Ba^{2+} which are soluble

All compounds containing carbonate (CO_3^{2-}), phosphate (PO_4^{3-}), chromate (CrO_4^{2-}) are insoluble except for Group I and NH_4^+ which are soluble

Model 2: Net ionic equations

When a soluble salt is placed in water, it separates into its ions. For example, sodium chloride is soluble.

$$NaCl_{(s)} + H_2O_{(l)} \rightarrow NaCl_{(aq)} \rightarrow Na^+_{(aq)} + Cl^-_{(aq)}$$

Example 1: Sodium nitrate reacts with potassium acetate in an aqueous solution.

In *double displacement* reactions, two ionic compounds react and switch cations.

$$NaNO_{3\,(aq)} + KC_2H_3O_{2\,(aq)} \rightarrow KNO_{3\,(aq)} + NaC_2H_3O_{2\,(aq)}$$

According to this "pencil and paper" reaction, potassium nitrate and sodium acetate are produced. However, if this reaction is actually carried out in an aqueous solution, nothing happens.

If we investigate this from the concept of a net ionic reaction, we can see why. First, we write all the compounds that soluble as ions.

$$Na^+_{(aq)} + NO_3^-{}_{(aq)} + K^+_{(aq)} + C_2H_3O_2^-{}_{(aq)} \rightarrow K^+_{(aq)} + NO_3^-{}_{(aq)} + Na^+_{(aq)} + C_2H_3O_2^-{}_{(aq)}$$

Next, we cross out any ions that are present on both the left (reactants) side and right (products) side of the reaction.

$$\cancel{Na^+} + \cancel{NO_3^-} + \cancel{K^+} + \cancel{C_2H_3O_2^-} \rightarrow \cancel{K^+} + \cancel{NO_3^-} + \cancel{Na^+} + \cancel{C_2H_3O_2^-}$$

The ions we cross out, which are unchanged on either side, are called *spectator ions* (they are just "standing around watching", hence spectator).

Both of the compounds on the right hand (products) side of the reaction are soluble. Therefore, no solid forms and *no reaction occurs*. The ions are all simply floating around together in solution.

Example 2: Strontium nitrate solution reacts with a potassium sulfate solution.

$Sr(NO_3)_{2\,(aq)} + K_2SO_{4\,(aq)} \rightarrow 2\,KNO_{3\,(aq)} + SrSO_{4\,(s)}$ Predict products and balance
(This is called Molecular equation)

sol sol sol **insol** Determine solubility

$Sr^{2+}_{(aq)} + 2NO_3^-{}_{(aq)} + 2K^+_{(aq)} + SO_4^{2-}{}_{(aq)} \rightarrow 2K^+_{(aq)} + 2NO_3^-{}_{(aq)} + SrSO_{4\,(s)}$
Write all soluble compounds as ions
(This is called an ionic equation)

$Sr^{2+} + \cancel{2NO_3^-} + \cancel{2K^+} + SO_4^{2-} \rightarrow \cancel{2K^+} + \cancel{2NO_3^-} + SrSO_4$ Cross out spectator ions

$Sr^{2+}_{(aq)} + SO_4^{2-}{}_{(aq)} \rightarrow SrSO_{4\,(s)}$ Write remaining ions/compounds

This final equation is the ***net ionic equation***.

Precipitation Reactions and Net Ionic Equations

Key Questions

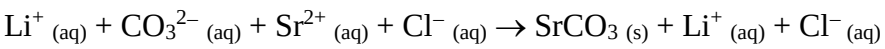
1. Define spectator ions?

2. In Example 1, what ions are spectators?

3. In Example 2, what ions are spectators?

4. In Example 2, what insoluble compound is formed?

5. For the reaction written below, what ions are spectators?



$$Li^{+}_{(aq)} + CO_3^{2-}{}_{(aq)} + Sr^{2+}{}_{(aq)} + Cl^{-}{}_{(aq)} \rightarrow SrCO_3{}_{(s)} + Li^{+}{}_{(aq)} + Cl^{-}{}_{(aq)}$$

6. In example 1, why is there no reaction when solutions of $NaNO_3$ and $KC_2H_3O_2$ are mixed?

7. If a reaction takes place in water, when is a reaction observed to occur? When is it observe not to occur?

Precipitation Reactions and Net Ionic Equations

Exercises

1. Write balanced **molecular**, **ionic**, and **net ionic equations** for each of the following. Follow the same steps given in example 2 above. If no reaction occurs, write **NR**.

(a) $Fe(C_2H_3O_2)_{2\ (aq)} + Ca(OH)_{2\ (aq)} \rightarrow$

Molecular Equation	
Ionic Equation	
Net Ionic Equation	

(b) $MgSO_{4\ (aq)} + AgNO_{3\ (aq)} \rightarrow$

Molecular Equation	
Ionic Equation	
Net Ionic Equation	

(c) $K_3PO_{4\ (aq)} + Cu(C_2H_3O_2)_{2\ (aq)}$

Molecular Equation	
Ionic Equation	
Net Ionic Equation	

(d) A solution of calcium hydroxide is added to a solution of iron (III) chloride

Molecular Equation	
Ionic Equation	
Net Ionic Equation	

(e) $FeI_{3\ (aq)} + Na_2SO_{4\ (aq)}$

Molecular Equation	
Ionic Equation	
Net Ionic Equation	

(f) $(NH_4)_2SO_{4\ (aq)} + Ba(NO_3)_{2\ (aq)}$

Molecular Equation	
Ionic Equation	
Net Ionic Equation	

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